Boletim da Sociedade Astronômica Brasileira, **32**, no. 1, 130-131

Simulations of the supercluster merger Abell 901/2 and the formation of jellyfish galaxies

Rafael Ruggiero[1], Rubens E. G. Machado[2], Fernanda V. Roman-Oliveira[3], Ana L. Chies-Santos[3], Gastão B. Lima Neto[1], Lia Doubrawa[2], & Bruno Rodríguez del Pino[4]

[1] Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo, R. do Matão 1226, São Paulo, Brazil
[2] Departamento Acadêmico de Física, Universidade Tecnológica Federal do Paraná, Rua Sete de Setembro 3165, Curitiba, Brazil
e-mail: `rubensmachado@utfpr.edu.br`
[3] Departamento de Astronomia, Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil
[4] Centro de Astrobiología, CSIC-INTA, Torrejón de Ardoz, 28850, Madrid, Spain

Abstract. The Abell 901/2 system is a galaxy cluster merger in which two small groups and two galaxy clusters are currently seen in route of collision. There are several galaxies, whithin each subcluster, with properties suggestive of jellyfish morphology. We aim to model the merger as a whole, including the four components, and explore how the gas properties in this environment correlate to the locations of the jellyfish galaxies in the observed system. We performed hydrodynamical *N*-body simulations tailored to reproduce the global mass distribution of the system and also its diffuse X-ray emission. There are boundary regions in each subcluster where gas moving along with the subcluster meets the diffuse gas from the remainder of the system. Our simulations indicate that jellyfish galaxies tend to be found preferentially close to such boundaries. In those regions, the ram pressure undergoes an increase of as much as three orders of magnitude within a few hundred kpc. This could lead to the intense rates of gas loss needed for jellyfish morphologies to arise.

Resumo. O sistema Abell 901/2 é uma fusão de aglomerados de galáxias na qual dois pequenos grupos e dois aglomerados de galáxias são vistos atualmente em rota de colisão. Existem várias galáxias, em cada sub-aglomerado, com propriedades sugestivas de morfologia de águas-vivas. Nosso objetivo é modelar a fusão como um todo, incluindo os quatro componentes, e explorar como as propriedades do gás neste ambiente se correlacionam com as localizações das galáxias águas-vivas no sistema observado. Realizamos simulações hidrodinâmicas de *N*-corpos para reproduzir a distribuição global de massa do sistema e também sua emissão difusa de raios-X. Existem regiões limítrofes em cada sub-aglomerado onde o gás que se move junto com o sub-aglomerado encontra o gás difuso do restante do sistema. Nossas simulações indicam que as galáxias de águas-vivas tendem a ser encontradas preferencialmente próximas a tais fronteiras. Nessas regiões, a pressão de arraste sofre um aumento de até três ordens de grandeza dentro de algumas centenas de kpc. Isso poderia levar a taxas intensas de perda de gás necessárias para causar a morfologia das águas-vivas.

Keywords. Galaxies: clusters: intracluster medium – Galaxies: clusters: individual: A901 – Galaxies: evolution

1. Introduction

In the standard cosmology, smaller structures collapse earlier and subsequent mergers give rise to progressively larger structures. In this context, galaxy clusters are the most massive bound systems. Merging galaxy clusters offer an ideal laboratory to study structure formation as well as the environments in which galaxies themselves evolve. Abell 901/2 (hereafter A901/2) is a complex unrelaxed system comprising four main structures: A901a, A901b, A902 and the Southwestern (SW) group (Gray, et al. 2004, 2009; Weinzirl, et al. 2017). Given their masses and current separations, we are probably witnessing the early stages of a multi-cluster merger. Mergers of clusters have often been studied by means of tailored simulations, aiming to model particular collisions and thus reconstruct their dynamical histories (e.g. Springel & Farrar 2007; Machado & Lima Neto 2013, 2015; Machado et al. 2015; Laganá, et al. 2019). However, dedicated simulations involving three or more clusters are rare; one example is a triple merger simulated by Brüggen, van Weeren & Röttgering (2012). When gas-rich galaxies move through the intracluster medium, ram pressure can cause them to lose gas. In the extreme case, this may give rise to the so-called ‘jellyfish’ morphology, in which a galaxy leaves behind a trail of stripped stars and gas. This phenomenon can also be studied with hydrodynamical simulations (e.g. Ruggiero & Lima Neto 2017).

2. Simulation setup

We attempt to explore the physical mechanisms involved in the formation of jellyfish galaxies in clusters. We model the A901/2 system as a collision of four substructures using *N*-body hydrodynamical simulations. Each subcluster is represented by 10^5 dark matter particles with a Hernquist (1990) density profile, and 10^6 gas particles with a Dehnen (1993) density profile. The main observational constraints are the masses of the subclusters (Heymans, et al. 2008) and their projected separations. For simplicity, we assume the orbits are all on the plane of the sky. We also assume that they are currently falling towards their centre of mass. Given their masses, the velocities required by virial equilibrium would be $\sim$1000 km/s. We draw random velocity components but imposing the sign of the cartesian coordinates such that they are all incoming. As a first step, we place four point masses at the current location of the clusters and then integrate their orbits backwards in time for 5 Gyr. This gives an educated estimate for the true initial conditions of the collision. Next, the actual *N*-body hydrodynamical initial conditions are introduced. Some fine-tuning is necessary because extended objetcts will have slightly different orbits than point masses. The simulations are performed with the Gadget-2 code (Springel 2005) and the evolution is followed for at least 5 Gyr. Finally, in the resulting best model, the subclusters reach the desired positions at the instant t =4.3 Gyr.

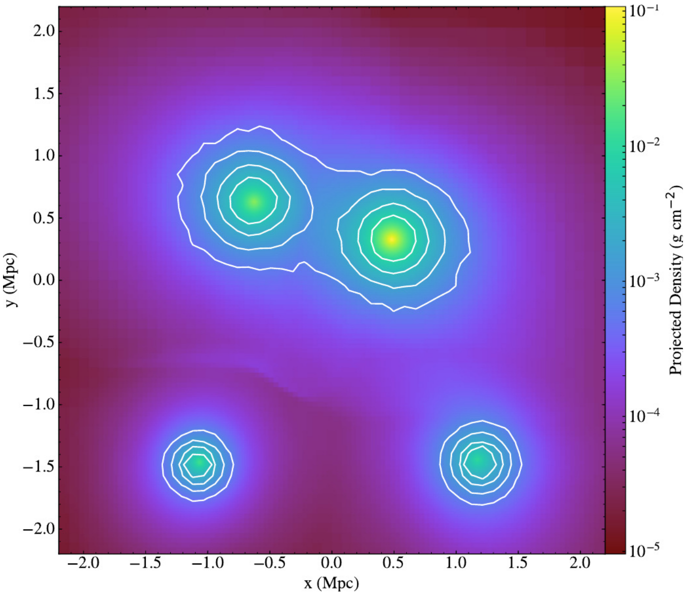

Figure 1. Projected gas density map for the best instant of the simulation.

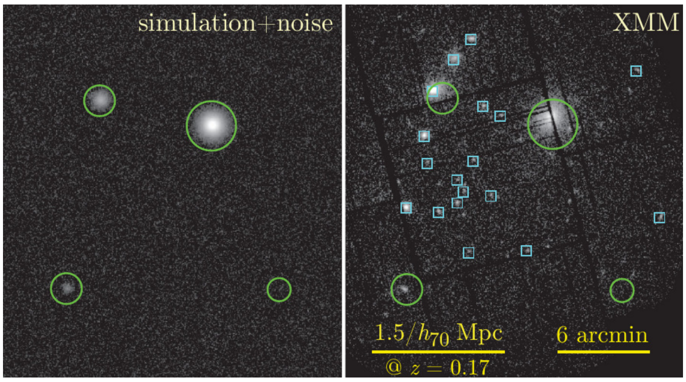

Figure 2. Mock X-ray simulated image with added noise (left) compared to the XMM-Newton observation (right).

3. Results

The best instant of the simulation is shown in Fig. 1 with the colors representing projected gas density. We use the gas properties to produce a mock X-ray image which can be more directly compared to observations (Fig. 2). We notice that the X-ray emission of the SW group is very weak, rendering it nearly undetectable. This is an indication that the model is a good approximation and should offer an adequate environment in which to study the effect of the intracluster medium (ICM) on the galaxies.

Ram pressure (Gunn & Gott 1972) $P_{\rm ram} = \rho_{\rm ICM} v_{\rm ICM}^2$ is computed using the densities and velocities of the ICM gas, in the reference frame of each subcluster. In the regions where the ICM of each subcluster meets the external environment, we find narrow (~100 kpc) boundaries across which ram pressure undergoes significant increases of up to three order of magnitude.

We next analyse whether these ram pressure boundaries are connected to the locations of the jellyfish galaxies. We measure the distance from each galaxy to the nearest boundary and find that jellyfishes are systematically closer to their respective nearest boundary than normal galaxies in the same sample (Gray, et al. 2009) and than a random dsitribution of points (Fig. 3). For further details, see Roman-Oliveira, et al. (2019) and Ruggiero, et al. (2019).

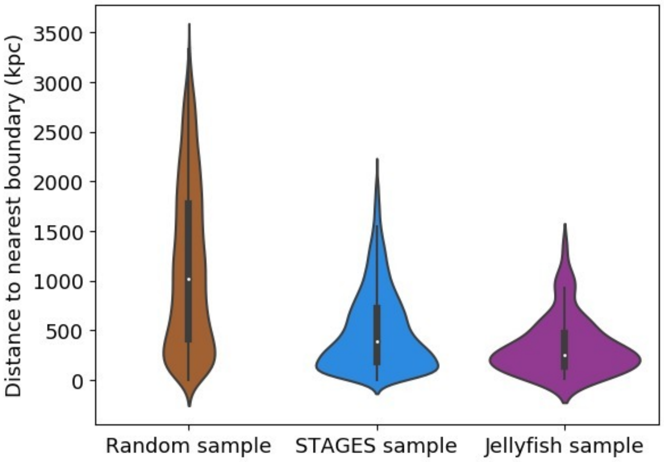

Figure 3. The distributions of distances from the galaxy to the nearest ram pressure boundary, for a random data distribution, for the galaxies in the STAGES sample, and for the jellyfishes in A901/2.

Acknowledgements. RR thanks the São Paulo Research Foundation, FAPESP, for the financial support (grant 15/13141-7). This work has made use of the computing facilities of the Laboratory of Astroinformatics (IAG/USP, NAT/Unicsul), whose purchase was made possible by the Brazilian agency FAPESP (grant 2009/54006-4) and the INCT-A. Simulations were carried out in part at the Centro de Computação Científica e Tecnológica (UTFPR). REGM acknowledges support from the Brazilian agency *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq) through grants 303426/2018-7 and 406908/2018-4. This study was financed in part by the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil* (CAPES) - Finance Code 001. ACS and FRO acknowledge funding from the Brazilian agencies *Conselho Nacional de Desenvolvimento Científico e Tecnológico* (CNPq) and the Rio Grande do Sul Research Foundation (FAPERGS) through grants PIBIC-CNPq, CNPq-403580/2016-1, CNPq-310845/2015-7, PqG/FAPERGS-17/2551-0001, PROBIC/FAPERGS and L'Oréal UNESCO ABC *Para Mulheres na Ciência*. GBLN thanks financial support from CNPq and FAPESP (2018/17543-0).

References

Brüggen M., van Weeren R. J., Röttgering H. J. A., 2012, MNRAS, 425, L76
Dehnen W., 1993, MNRAS, 265, 250
Gray M. E., Wolf C., Meisenheimer K., Taylor A., Dye S., Borch A., Kleinheinrich M., 2004, MNRAS, 347, L73
Gray M. E., et al., 2009, MNRAS, 393, 1275
Gunn J. E., Gott J. R., 1972, ApJ, 176, 1
Hernquist L., 1990, ApJ, 356, 359
Heymans C., et al., 2008, MNRAS, 385, 1431
Laganá T. F., Souza G. S., Machado R. E. G., Volert R. C., Lopes P. A. A., 2019, MNRAS, 487, 3922
Machado R. E. G., Lima Neto G. B., 2013, MNRAS, 430, 3249
Machado R. E. G., Lima Neto G. B., 2015, MNRAS, 447, 2915
Machado R. E. G., Monteiro-Oliveira R., Lima Neto G. B., Cypriano E. S., 2015, MNRAS, 451, 3309
Roman-Oliveira F. V., Chies-Santos A. L., Rodríguez del Pino B., Aragón-Salamanca A., Gray M. E., Bamford S. P., 2019, MNRAS, 484, 892
Ruggiero R., Lima Neto G. B., 2017, MNRAS, 468, 4107
Ruggiero R., Machado R. E. G., Roman-Oliveira F. V., Chies-Santos A. L., Lima Neto G. B., Doubrawa L., Rodríguez del Pino B., 2019, MNRAS, 484, 906
Springel V., 2005, MNRAS, 364, 1105
Springel V., Farrar G. R., 2007, MNRAS, 380, 911
Weinzirl T., et al., 2017, MNRAS, 471, 182